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# A Self-Calibration Antenna Array System with Moving

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**Abstract** - In this paper, an antenna array system with self-calibration capability to the antenna element position errors is proposed. The essential concept of self-calibration is to detect the element positions by using near field reference sources. The estimated position information is further substituted into the beamforming process to correct the distorted pattern of the antenna array. To validate the proposed concept, a test bed with a "distorted" eight element array is set up. With the proposed calibration architecture, the estimation of the position errors is within 7% of the free space wavelength. Based on the estimation information, the array pattern can thus be synthesized

## I. INTRODUCTION

Calibration of the antenna array system has become an important part of the array system because the system performance is usually very sensitive to the phase errors. Such errors may significantly shift the direction of antenna beams and nulls, thus affect the system SNR performance [1]. Generally, the error existing in the phased array system comes from two parts- circuit error and element location error or position error. A majority of work has been done to calibrate the circuit error [2-3]. The element position error usually exists in some special communication systems called distorted phased array, such as balloon communication systems, in which the antenna array is built on the balloon's surface, with changing spacing between the elements all the time. Some

into two steps-first, an estimation algorithm to estimate the position error. The basic principle is somewhat like that of GPS receivers. A signal is employed in this algorithm so that the circuit error can be cancelled out. The second step is circuit error calibration.

The key technique of this system is to separate the position error and circuit error with near field source coding technique makes it possible for the multiple sources to share one frequency channel. The information from the calibration system is used to adjust the weighting coefficients to restore the correct pattern.

This paper is organized as follows. Section II presents the basic theory of this calibration algorithm. Section III shows the effectiveness of the proposed approach, a test bed is developed with an 8-element distorted array. Section IV provides the overview of such a test bed. Section V presents the measured results to demonstrate the performance of the proposed approach. Finally, conclusions are made in section VI.

## II. CALIBRATION THEORY

### A. Position calibration:

To calibrate the three dimensional moving antenna element, four sources are needed.

researchers have proposed their own **calibration** methods in [4-5]. however, most of those ideas are developed for certain scenarios and can not be extended for general applications. Real world phased array systems usually require a fast, simple, compact and robust **calibration** process.

In this paper, a self-**calibration** scheme for both the position error and circuit error has been presented. The essential idea is to use near field reference sources. A few advantages are associated with the proposed configuration. First, the existence of self-calibrating sources brings the **calibration** scheme more adaptability, even for battlefield systems in a hostile environment. Second, only very limited number the reference sources are required and these sources can be practically mounted on rigid frames. Third, the approach is insensitive to the absolute **delay** and **phase** error of the reference source, which make the approach more robust. The **calibration** process is divided

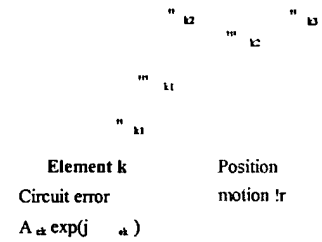


Fig.1 Geometry of array **calibration**

Fig.1 describes the basic idea of this position

algorithm. The four **calibration** sources are positioned close to the receiving antenna at the kth element in the smart antenna array. This element has a three

position motion  $r$ . Furthermore, there is circuit **phase** error  $\phi_k$  in the branch  $k$ , caused by element's aging or circuit connectors and solders.  $\phi_k$ ,  $k=1,2,3,4$  is the **phase** shift created by the distance between sources and element  $k$ . In order to make the algorithm more robust, three basic assumptions have to be made.

- 1) Four **calibration** sources are fixed in the near field of the antenna array but still far field of the each antenna.
- 2) Four sources are synchronized or the **phase** difference is known.
- 3) The position motion is very small compared with the distance between sources and the element.

The purpose of this algorithm is to use the **phase** information to calibrate the position. However, the circuit **phase** error  $\phi_k$  does always exist in the receiving signals. Here, the **phase** difference between two sources' signal at the receiving element  $k$  is calculated so that cancelled.

$$\begin{aligned} &= \frac{1}{2} \left( \phi_k - \phi_{k-1} \right) \left( \phi_k + \phi_{k-1} \right) \\ &= \frac{1}{2} \left( \phi_k - \phi_{k-1} \right) \left( \phi_k + \phi_{k-1} \right) \end{aligned} \quad (1)$$

the original position of the element can be **calibration** position or virtual position. The virtual position is that we can assume the moving around a center point. In each time position motion according to the virtual position detected so that we can "position" the antenna. *B. Source coding:*

The four near field sources share the same special coding technique is needed to separate receiving antenna. Here, orthogonal sequences are used. The four synchronized sources send out four orthogonal digital signals  $s_1(t), s_2(t), s_3(t)$ . These four digital signals share the same period; inside one period, they satisfy:

$$\begin{aligned} &s_i(t) s_j(t) = 0 \\ &s_i(t) s_j(t) = M \end{aligned}$$

Hence, we can assume the total baseband converter at the receiving antenna  $k$  becomes

Where  $\# = 1, 2, 3$ .

$\Delta \phi_k$  and  $\Delta \phi_k'$  represents the **phase** difference before and after motion.

Thus the circuit **phase** error term is removed. The next step is to construct the **relationship** between **phase** information and position motion  $r$ . Due to the assumption (3), a **linear relationship** can be easily found:

$$(- + \Delta \phi_k) = n_k r \quad \# = 1, 2, 3 \quad (2)$$

Obviously, the position motion is proportional to the difference of the **phase** difference. Here, a random **phase** noise term  $n_k$  is added to simulate the random error in extracting the **phase** information from the receiving signals. Using proper DSP algorithm, such as Kalman filters, will give the best estimation of the unknowns under the noisy condition.

The reason we need four **calibration** sources is that the position motion is three-dimensional and at least three equations like (2) can solve for the three unknowns ( $x$ ,  $y$ ,  $z$ ).

$$\begin{pmatrix} x_k \\ y_k \\ z_k \end{pmatrix} = \mathbf{H} \begin{pmatrix} x_1 & x_2 & x_3 \\ y_1 & y_2 & y_3 \\ z_1 & z_2 & z_3 \end{pmatrix} \quad (3)$$

Where  $\mathbf{H}$  is the coefficients matrix which is only the function of element  $k$ 's original position ( $x_k, y_k, z_k$ ) and source positions. Thus the new position of the element  $k$  can be easily obtained.

After detecting the new position of the each antenna element, the new weighting coefficients can be calculated with the adaptive beamforming technique such as sample matrix inversion (SMI). One thing needs to mention is that

$$x(t) = \sum_{n=1}^N s_n(t) \exp(j \Delta \phi_n) A_n$$

We can use the DSP algorithm like match separate the information coming from the

$$\sum_{n=1}^N s_n(t) x_n(t) = \sum_{n=1}^N M \exp(j \Delta \phi_n) A_n$$

Hence, the formulations (1-3) can be used position **calibration**.

The length of the orthogonal codes will affect **calibration's** precision. Usually, the long give the better results. However, the long take more data collection time and DSP cost. The code length must be carefully selected according to the moving speed of element and the required accuracy.

**C. Circuit error calibration:** Circuit **calibration** can be realized after the **calibration**. Since the position error has been compensated, which means  $\Delta \phi_k$  and  $R_k$  are known, the information  $A_k \exp(j \Delta \phi_k)$  can be extracted.

$$error_k = A_k \exp(j \Delta \phi_k)$$

Change the weighting coefficients, the path can be compensated:

$$W_k' = W_k + error_k$$

### III. CIRCUIT OVERVIEW

A system including one receiver and two

sources is constructed to test the technique described in section II. Assume that a mechanic motion causes the smart antenna receiver to distort from a uniform half-wavelength array to a non-uniform array. As a result, the original weighting coefficients which are calculated from the uniform array are no longer suitable to the distorted

patch array to have low mutual coupling. Each element has a 20dB sub-harmonic I/Q mixer, which convert signals directly to IF signals. Since the same antenna is used as the transmitter, those IF signals are band signals. An anti-parallel diode mixer

array. With the two fixed near-field sources, the element spacing error of the non-uniform array can be detected then the new weighting coefficients can be calculated to calibrate the main beam direction and null direction. The reason to use only two transmitters instead of four is that only one-dimensional motion of the antenna element needs to be calibrated.

Fig. 2 Near-field calibration sources

Fig.2 shows the circuitry of two near-field calibration sources. Two synchronized digital sources generate 100KHz orthogonal sequences "1100" and "1010". These two digital signals are modulated with 5.828GHz synchronized LO carrier. Two transmitter antennas are quasi-Yagi antennas, which are broad bandwidth and broad beam width. Because the RF signals coming out of the mixers pass the same length of transmission line or cables then are transmitted out by the same antenna, the RF signals from the antenna can be considered as synchronized signals.

Fig.3 shows the receiver with the distorted array. The distorted array is constructed by eight compact subdivided square microstrip patch antennas, which has a size reduction of 60% compared to the conventional square microstrip patch antenna [6]. This advantage can make the

offset is designed for this system. The LO mixer is 2dBm. In order to implement in-quadrature-phase mixers, 45° offset signal path in order to achieve uniform signals over the RF bandwidth. As a result signals before low pass filter in element k as:

$$I_f(t) = s_1(t) \sin(\omega_c t + \theta_1) + s_2(t) \sin(\omega_c t + \theta_2)$$

Notice that in (9), the amplitude information is

After low pass filter, I and Q signals enter oscilloscope to realize the A/D converter function. Then the sampled data are collected and transferred to PC. A matlab code works to realize the calibration and digital beamforming.

#### IV. MEASURED RESULTS

A virtual position of each element is set to original array is a half wavelength uniform near field calibrated sources are fixed in (0, 0.156m) high of the uniform array's center

Source 1

Receiver

Fig. 4 Location of the calibration sources and receiver

Fig. 5 shows the measured base band signal and element one of the receiver. Source one transmits '1100' with the amplitude 0.1V. Source two transmits '1010' with the amplitude 0.1V offset 0.1V. The base band I/Q signals are also offset, which will affect the precision of the measurement. Equation (9) proposes a good way to remove the offset. From (9), in the first and last bit positions, the signals are always equal amplitude but negative

information, the DC offset can be calculated then be removed from the I(t) and Q(t).

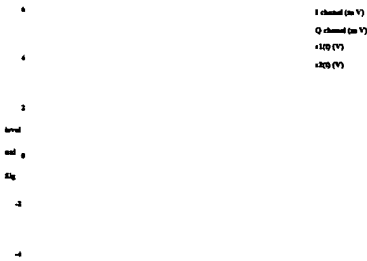


Fig. 5 Measured base band signals at the sources and receiver

(element one)

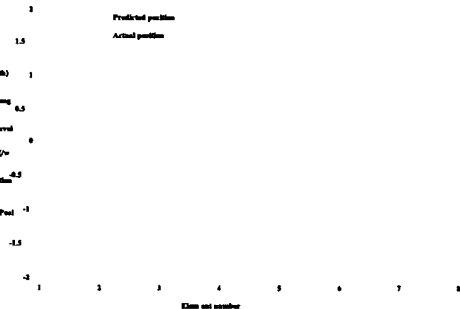


Fig.6 Predicted position and actual position of each element

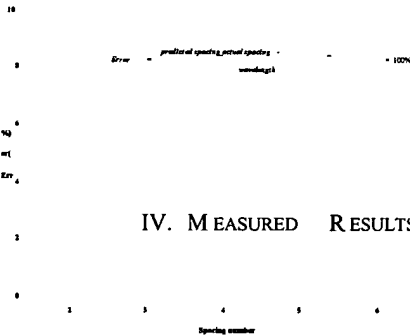


Fig. 7 Array spacing error

spacing, which shows our calibration alg enough to the calibration sources' positic Fig.7 shows the spacing error of each ele the free space wavelength. The maximum about 6% of the wavelength, which is too the far field pattern. Fig.8 shows the syntl SDMA communication, with two far field and -30% respectively. Because of the ele original pattern is highly distorted, with tl null position shifted. After the position a new weighting coefficients applied, the p:

V. CONCLUSIO

A novel array calibration scheme has a test bed has been set up to validate the c measurement results show that it is a prec calibration can be carried out. The spacis is less than 7%. The distorted array patter using the estimated element position. The further developed to measure and calibrat error.

A CKNOWLEDGEMI

The authors would like to thank Jiyong Jeon, Kevin Leong and Takahide Nishio i they rendered.

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Fig. 8 Synthesized beamforming result (SOI: +30 °, SNOI: -30 °)

Fig.6 shows the predicted position and actual position of each element. A common position error exists in each element, and this error is caused by position error of the sources. However, this error will not affect the array

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